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Water-Surface Elevations of Wetlands and Nearby Wells at Arnold Air Force Base, Near Manchester, Tennessee

Prepared by the
U.S. Geological Survey

in cooperation with the
UNITED STATES AIR FORCE,
ARNOLD AIR FORCE BASE

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By WILLIAM J. WOLFE and DONALD E. LEAGUE

U.S. GEOLOGICAL SURVEY

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Nashville, Tennessee
1996

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CONTENTS

FIGURES

TABLES

CONVERSION FACTORS, VERTICAL DATUM, AND WELL-NUMBERING SYSTEM

Multiply	By	To obtain
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
cubic foot per second (ft^3/s)	0.0283	cubic meter per second

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic reference datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Well-numbering system: The U.S. Geological Survey assigns each well in this report a local well number and a station identification number. The local well number is used as a concise label for a well. The station identification number is used as an identifier for site data stored in the national computer system of the U.S. Geological Survey. These numbering systems are used in addition to the well numbers assigned by Arnold Engineering Development Center.

The local well number in Tennessee consists of three parts: (1) an abbreviation of the name of the county in which the well is located; (2) a letter designating the 7.5-minute quadrangle on which the well is plotted; and (3) a number generally indicating the numerical order in which the well was inventoried. For example, the local well number Cf:G-067 indicates that the well is located in Coffee County on the "G" quadrangle and is identified as well 67 in the numerical sequence. Quadrangles are lettered from left to right, beginning at the southwest corner of the county.

The station identification number is a unique number for each well based on latitude and longitude. The number consists of 15 digits. The first 6 digits denote degrees, minutes, and seconds of latitude; the next 7 digits denote degrees, minutes, and seconds of longitude; and the last 2 digits sequentially identify wells within a 1-second grid.

Water-Surface Elevations of Wetlands and Nearby Wells at Arnold Air Force Base, Near Manchester, Tennessee

By William J. Wolfe *and* Donald E. League

ABSTRACT

Surface-water stage, ground-water elevations, rainfall, and streamflow were monitored at or near four wetland sites at Arnold Air Force Base, Tennessee. Sinking Pond and Westall Swamp contain sinkholes with internal relief greater than 7 feet. Tupelo Swamp and Goose Pond are shallow depressions with less than 5 feet internal relief. Stage rose and fell abruptly in the two sinkhole wetlands. Water depths ranged from 0 to 11.4 feet in Sinking Pond and from 0 to 8.5 feet in Westall Swamp. Water levels in wells adjacent to the sinkhole wetlands also rose and fell abruptly, corresponding closely to surface-water elevations throughout periods of high stage. The two shallow depressions filled and drained more gradually, but remained flooded longer than the sinkhole wetlands. The maximum recorded water depths were 3.5 feet in Tupelo Swamp and 2.3 feet in Goose Pond. Water levels in nearby wells remained lower than surface-water elevations in the shallow depressions throughout the study period.

INTRODUCTION

Arnold Air Force Base (AAFB) occupies about 40,000 acres in Coffee and Franklin Counties, Tennessee (fig. 1). The AAFB reservation contains about 600 acres of wetlands (Benham Group, 1989). The wetlands are concentrated in the northeastern part of AAFB (fig. 2), which lies in the poorly drained Barrens of the Highland Rim (Killebrew and Safford, 1874; Miller, 1974; Luther, 1977; Smalley, 1983). Wetlands at AAFB and similar Barrens sites support numerous rare or protected plants and animals including coastal-plain plant species that are generally absent in upland areas of the southeastern United States (Benham Group, 1989; Ellis and Chester, 1989; Patterson, 1989). Goose Pond and Sinking Pond are Registered Natural Landmarks, and Sinking Pond is recognized as a research natural area by the American Society of Foresters (Benham Group, 1989).

The distinctive wetlands on AAFB represent a significant environmental asset as well as a constraint on development in parts of the base (Benham Group, 1989). Arnold Engineering Development Center (AEDC), an aerospace testing facility, occupies about 4,000 acres just south of the greatest concentration of wetlands on AAFB (fig. 2). Previous studies have documented ground-water contamination at AEDC and elsewhere in and around AAFB (Benham Group, 1989; Haugh and others, 1992). Dewatering at one of the AEDC test facilities, the J4 rocket test cell, imposes a stress on the local ground-water system (Haugh and Mahoney, 1994).

The proximity of the wetlands to industrial activity at AEDC represents potential for environmental degradation at ecologically sensitive and valuable sites. Evaluation of that potential requires an understanding of the hydrology of the wetlands in relation to the surrounding area. Two important aspects of wetland hydrology are water regime (the depth, duration, and frequency of flooding) and the relation between wetland sites and the local ground-water system (Carter and others, 1979; Carter, 1986; Mitsch and Gosselink, 1993). Together, these aspects of wetland hydrology provide an important basis for assessing the management implications of climate change, water-table fluctuations, and similar perturbations.

Information on the hydrology of distinctive wetland areas should provide insights on how these ecosystems become established, persist, and develop. Several studies have suggested a close relation

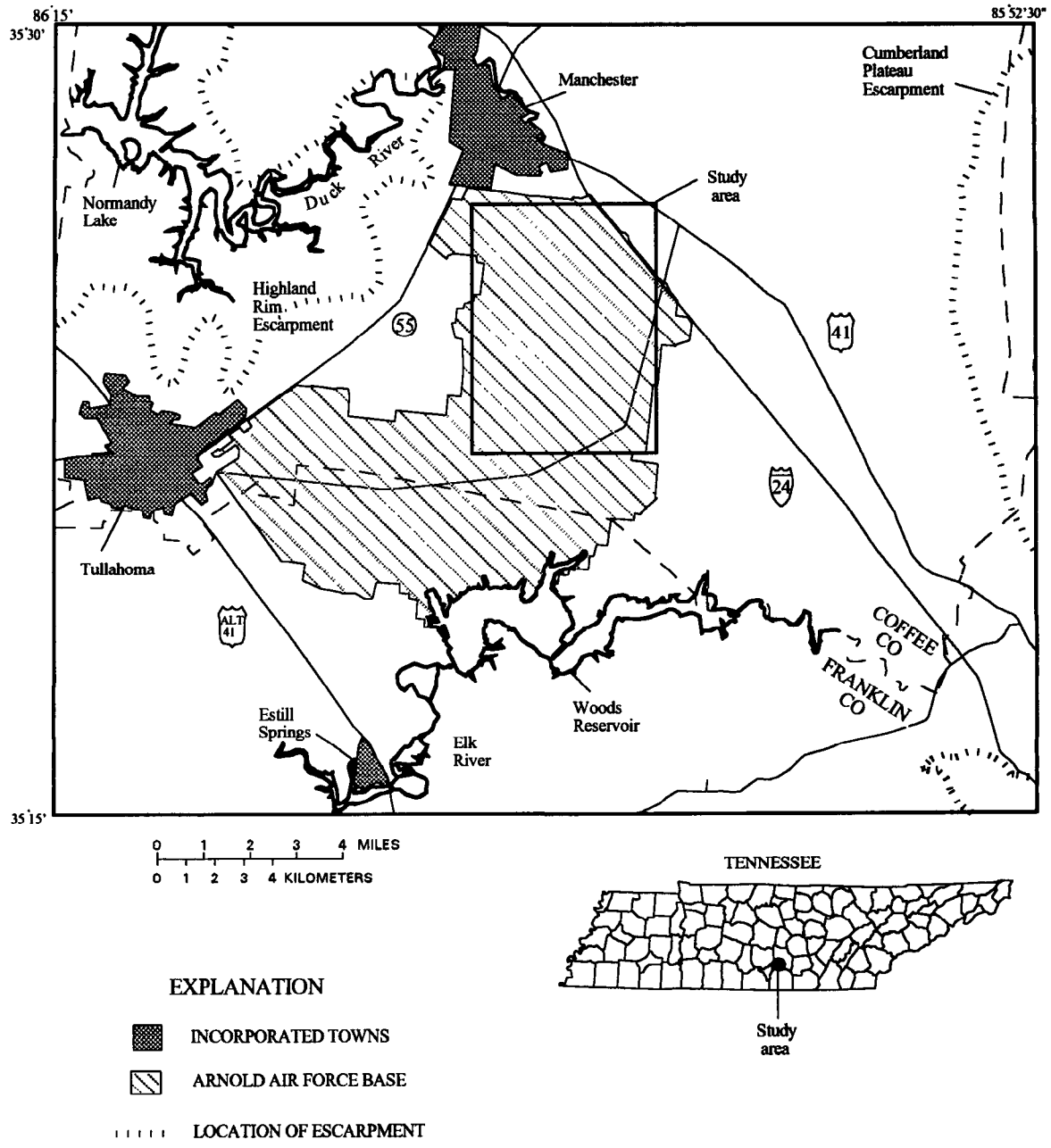

Figure 1. Location of Arnold Air Force Base and surrounding area.

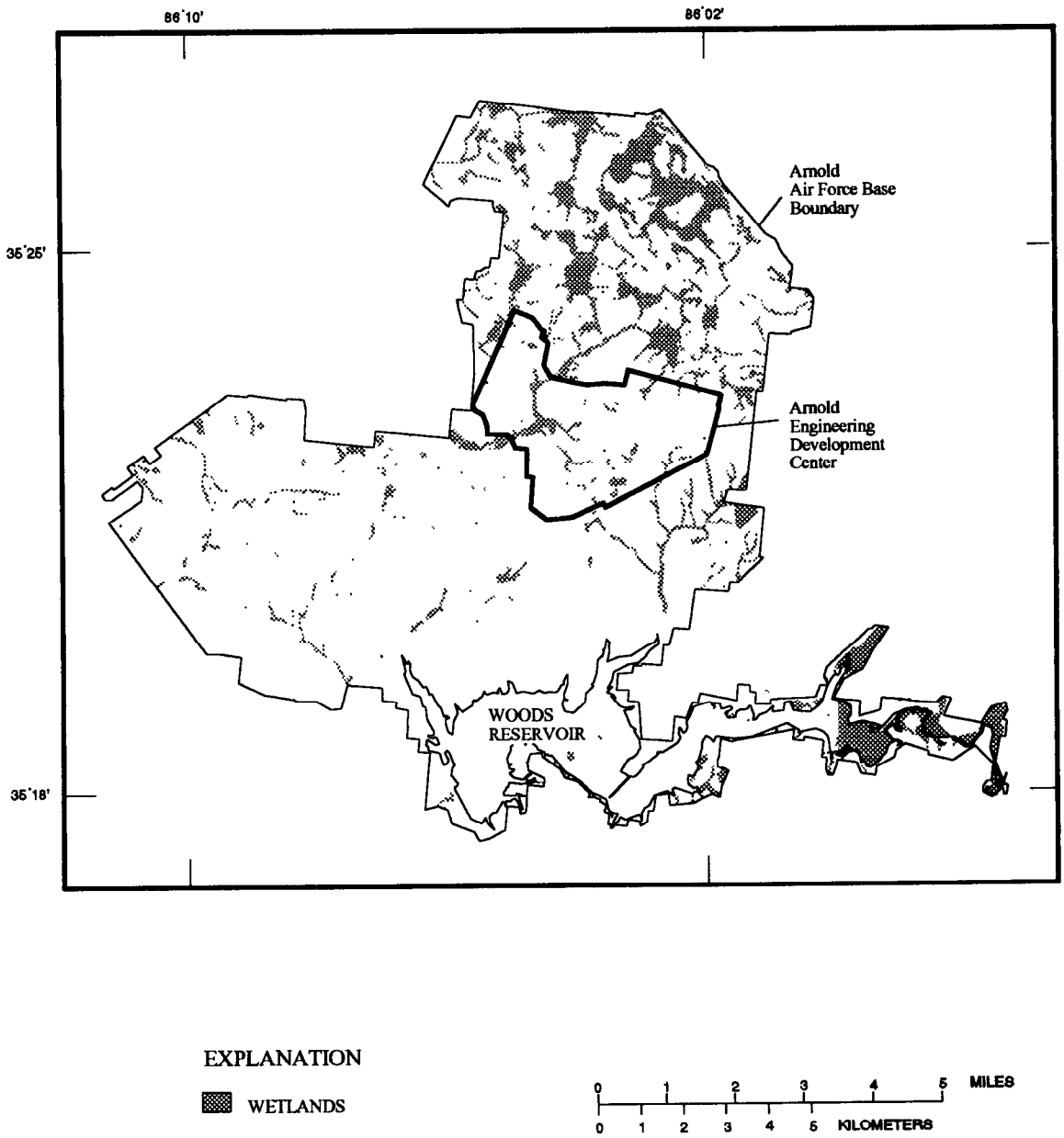

Figure 2. Location of wetlands and Arnold Engineering Development Center at Arnold Air Force Base.

between topography, flooding patterns, and vegetation zonation in Barrens wetlands (Ellis and Chester, 1989; Patterson, 1989; Bingham and Roberts, 1994), but none have included detailed hydrologic observations. Improved understanding of the hydrology of the wetlands at AAFB should be transferable to other wetland sites in the Barrens and similar settings. In order to provide such an understanding, the U.S. Geological Survey (USGS), in cooperation with the U.S. Air Force and Arnold Air Force Base, conducted a hydrological investigation of selected wetlands at AAFB. The purpose of the investigation was to quantify the water regimes of representative wetlands and to determine their relation to the hydrologic system at AAFB.

Purpose and Scope

This report presents surface- and ground-water data collected at and near selected wetland sites on AAFB between October 1, 1992 and February 15, 1995. The data include: daily mean water levels from four seasonally flooded ponds; daily rainfall at one seasonally flooded pond and at a nearby stream gage; daily mean discharge at two sites along intermittent streams; and well-construction details and daily mean water levels from 11 wells.

Study Area

The study was conducted in the northeastern part of AAFB (fig. 1). Topography of the study area is typical of the Barrens (Burchett, 1977; Smalley, 1983), consisting of well-drained slopes and divides, poorly drained upland flats and depressions, and low-gradient, seasonally flowing streams. Soils range from well drained to poorly drained and are developed on limestone residuum.

Vegetation is generally correlated with topography, drainage, and soil (Patterson, 1989). Well-drained ridges and slopes support deciduous trees such as scarlet oak, southern red oak, and mockernut hickory, except where cleared or planted in pines. Moister, moderately well-drained slopes are characterized by white oak, hornbeam, sourwood, and yellow poplar. The vegetation of poorly drained sites often includes sweet gum, black gum, and red maple. Some of the wettest sites support single-species stands of coastal-plain trees such as willow oak, overcup oak, and water tupelo (Benham Group, 1989; Patterson, 1989). Other poorly drained sites are occupied by emergent herbaceous vegetation and shrubs (Benham Group, 1989).

A striking feature of some wetland sites is the presence of well-developed sinkholes with steep sides and internal relief of 7 feet or greater. Other sites that support water-tolerant vegetation are shallow depressions with less than 5 feet of internal relief. The distinction between well-developed sinkholes and shallow depressions has been noted at wetland sites elsewhere on the Highland Rim (Ellis and Chester, 1989).

Geology in the area of AAFB is dominated by flat-lying Mississippian limestones and cherty limestones. Most of the study area is mapped as Upper Mississippian Warsaw and St. Louis Limestones (Wilson, 1976). Both units are heterogeneous, including lenses and beds of sand, silt, and chert. In the study area they are weathered to clay-rich residuum with inclusions of chert and limestone float. The uppermost unit of relatively unweathered bedrock is the Lower Mississippian Fort Payne Formation. The Fort Payne Formation consists primarily of chert, limey chert, and cherty limestone with interbedded units of shale and shaley limestone. In the study area, this formation generally contains less than 50 percent calcium carbonate (Hershey and Maher, 1963; Burchett, 1977). The Fort Payne Formation is underlain by the Upper Devonian/Lower Mississippian Chattanooga Shale (Wilson, 1976; Burchett, 1977; Benham Group, 1989).

Interaction between wetlands and ground water at AAFB is likely to involve the Highland Rim aquifer system—those geologic units that overlie the Chattanooga Shale (Brahana and Bradley, 1986; Haugh and Mahoney, 1994). The primary aquifers are, from top to bottom, the shallow aquifer, the Manchester aquifer, and the Fort Payne aquifer. The Chattanooga Shale forms the base of this ground-water system (Haugh and Mahoney, 1994).

The shallow aquifer consists of 5 to 75 feet of silt and clay and includes the soil cover and root zone. The shallow aquifer acts as a leaky confining unit across much of AAFB.

The Manchester aquifer, a product of the weathering of the lower Warsaw Limestone and the Fort Payne Formation (Burchett and Hollyday, 1974), is the most productive aquifer. The upper part of the Manchester aquifer consists of chert gravel, weathered limestone and rubble. The lower part includes fractures and solution openings in bedrock, primarily near the top of bedrock in the Fort Payne Formation, but in

some cases at depths of 80 feet or more below the top of bedrock (Haugh and others, 1992). The wide variation in thickness and physical properties in this aquifer and the existence of preferential flow paths along fractures and other structural features results in relatively complex patterns of ground-water flow (Haugh and Mahoney, 1994).

The Fort Payne aquifer consists of that part of the Fort Payne Formation which is relatively dense, with few small fractures or solution openings. The thickness of this aquifer is variable, depending on the depth of the weathering profile.

The relative importance of the shallow aquifer and the upper and lower parts of the Manchester aquifer varies across AAFB. In general, the northern part of the base is characterized by weathering profiles less than 50 feet thick (Haugh and others, 1992) and a high concentration of solution openings in the Fort Payne Formation (Haugh and Mahoney, 1994). The shallow aquifer and the upper part of the Manchester aquifer are more important in the southern part of AAFB where the regolith is relatively thick and rich in coarse-grained chert. The relatively greater density and coherence of the Fort Payne Formation in the southern part of AAFB limit ground-water flow in the lower part of the Manchester aquifer (C.J. Haugh, U.S. Geological Survey, oral commun., 1995).

SITE SELECTION AND DATA COLLECTION

Four sites were selected for continuous hydrologic monitoring (fig. 3). Sinking Pond, Westall Swamp, and Goose Pond are named water bodies that appear on the USGS 1:24,000-scale Manchester quadrangle. The fourth site is a small depression north of Sinking Pond that supports a single-species stand of water tupelo. For the purpose of this report, this site is referred to by the informal name "Tupelo Swamp."

Sinking Pond and Westall Swamp are seasonally flooded depressions that support forests of water-tolerant oaks and other trees. Both include well-developed sinkholes with relatively steep sides and about 10 feet of internal relief. For this report, internal relief is defined as the difference in elevation between the deepest part of a wetland and its surface-water spillway. Goose Pond and Tupelo Swamp are shallow depressions with less than 5 feet of internal relief.

Ponded water levels were monitored with a single continuous-stage recorder at each of the four wetland sites. A fifth stage recorder was installed on the channel running from Tupelo Swamp into Sinking Pond. This site, designated Sinking Pond inflow (fig. 3), drains an area of 0.22 square miles (mi^2), about 17 percent of the 1.29 mi^2 catchment of Sinking Pond (table 1). A sixth continuous-stage recorder, designated Sinking Pond outflow, was located at the culvert south and downstream of Sinking Pond (fig. 3). The Sinking Pond catchment represents 84 percent of the 1.54 mi^2 drained by the Sinking Pond outflow gage (table 1). Discharge was measured periodically at Sinking Pond inflow and Sinking Pond outflow; the relation of stage to discharge was determined to provide continuous records of flow at these sites.

Daily rainfall was monitored at two sites. One tipping-bucket rain gage was established at the Westall Swamp stage recorder. For periods of missing record at the Westall Swamp rain gage, data from a second

Table 1. Gage data for surface-water stations at Arnold Air Force Base wetlands

[d-m-s, degrees-minutes-seconds; ft asl, feet above sea level; mi^2, square miles]

Station name	USGS Site identification	Latitude and longitude (d-m-s)	Station type	Gage Datum (ft asl)	Drainage area (mi^2)
Sinking Pond	03596075	35° 24' 36" N 86° 04' 11" W	Continuous stage	1,053.25	1.29
Westall Swamp	035960815	35° 24' 41" N 86° 04' 46" W	Continuous stage	1,056.84	.58
Tupelo Swamp	03596073	35° 25' 07" N 86° 03' 45" W	Continuous stage	1,066.98	.05
Goose Pond	035785012	35° 23' 11" N 86° 01' 33" W	Continuous stage	1,056.53	.12
Sinking Pond inflow	03596074	35° 25' 04" N 86° 03' 32" W	Continuous discharge	1,027.69	.22
Sinking Pond outflow	035960755	35° 24' 00" N 86° 03' 41" W	Continuous discharge	1,012.38	1.54

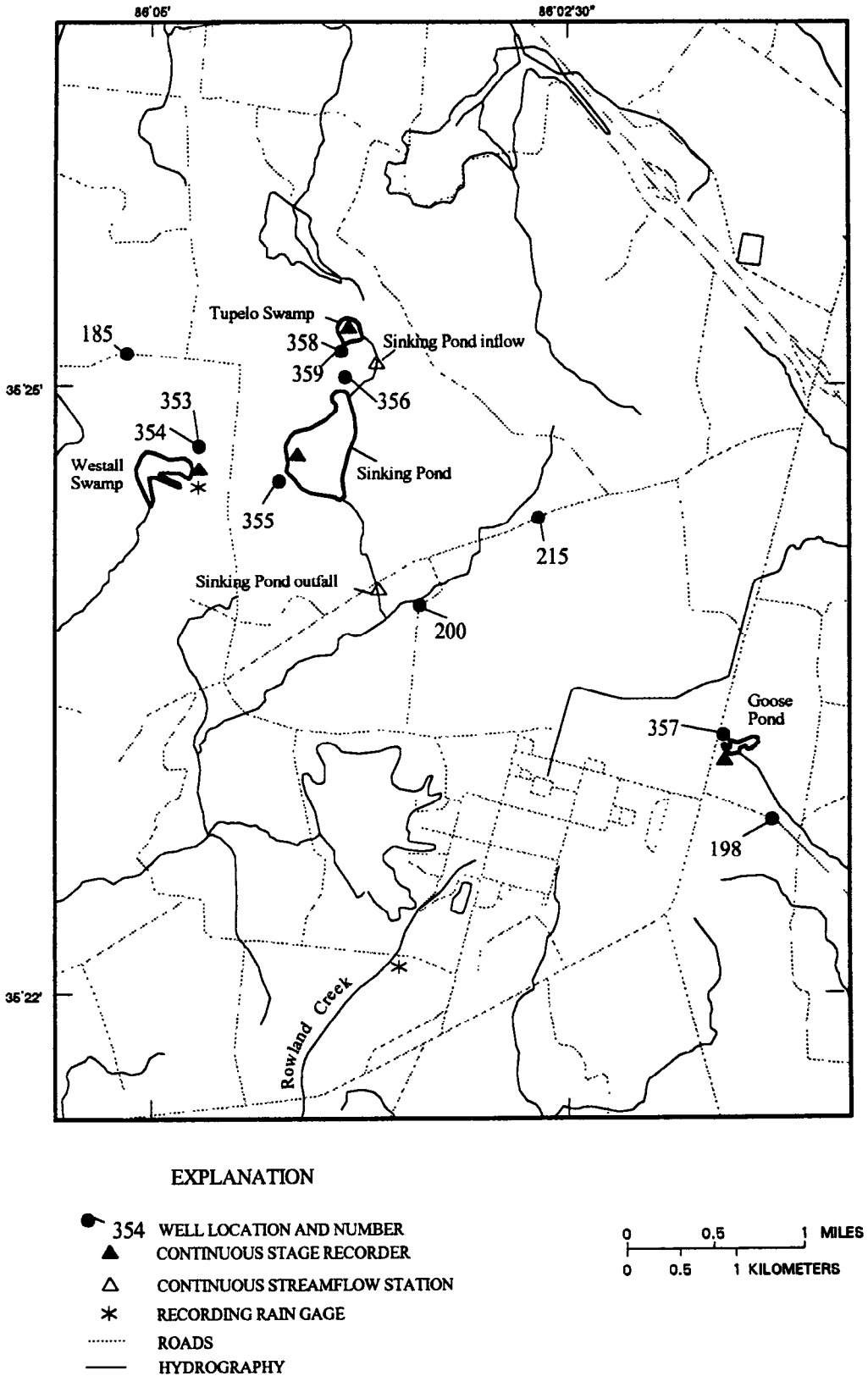

Figure 3. Location of monitored wetland sites and wells.

tipping-bucket rain gage on Rowland Creek, about 3 miles from the Westall Swamp gage (fig. 3), were used to estimate rainfall in the Sinking Pond/Westall Swamp area.

Ground-water levels were continuously monitored at 11 wells (fig. 3). Seven new wells were constructed near the continuously monitored wetland sites, and four pre-existing wells in the study area were monitored. Two wells were constructed at Sinking Pond. One well (AEDC-355) was located on the southwest side of the pond, adjacent to the stage recorder. The second (AEDC-356) was located on the north side of the pond. Both were drilled to the top of bedrock and screened in the upper part of the Manchester aquifer (table 2).

At Westall Swamp, two wells were drilled in close proximity to the stage recorder. One well (AEDC-353) was drilled in bedrock and screened in the lower part of the Manchester aquifer. The second well (AEDC-354) was drilled to the top of bedrock and screened in the upper Manchester aquifer. Similarly, wells AEDC-358 and AEDC-359 were installed and monitored next to the Tupelo Swamp stage recorder; they were screened in the upper and lower parts of the Manchester aquifer, respectively. Well AEDC-357 was drilled next to Goose Pond and screened in the shallow aquifer. A pre-existing well (AEDC-198), located about 0.75 mile southeast of Goose Pond (fig. 3) and screened in the Fort Payne aquifer (table 2), was also monitored.

Water levels in three other pre-existing wells were monitored. Well AEDC-185 is northwest of the Sinking Pond/Westall Swamp area (fig. 3) and is screened in the lower Manchester aquifer (table 2). Wells AEDC-200 and AEDC-215 are southeast of Sinking Pond (fig. 3) and screened in the lower and upper Manchester aquifer, respectively (table 2). Elevations above sea level were established for all wells and surface-water gages.

WATER-SURFACE ELEVATIONS AND DISCHARGE

The hydrographs of Sinking Pond and Westall Swamp are similar (figs. 4 and 5). The most striking features of the hydrographs are the abruptness and magnitude of the seasonal rises and falls. For example, on November 3, 1992, Sinking Pond rose 6.8 feet and Westall Swamp rose 4.8 feet in less than 24 hours. Subsequent seasonal rises and falls were similar in magnitude and abruptness. Recorded water-surface elevations in Sinking Pond, in feet above sea level, ranged between a fully drained minimum of 1,053.9 to a maximum of 1,065.4 (fig. 4) with corresponding maximum water depths of 0 to 11.5 feet. In Westall Swamp, recorded water-surface elevations covered a range of 8.5 feet from 1,058.0 (fully drained) to 1,066.5 feet above sea level (fig. 5).

Recorded water levels in Sinking Pond and Westall Swamp were closely related to those in nearby wells. Beginning at the seasonal rise and continuing through much of the periods of inundation, the water level in the well on the southwest side of Sinking Pond (AEDC-355) was essentially identical to that of the pond surface (fig. 4). Water levels in the well on the north end of Sinking Pond (AEDC-356) rose 1 to 5 feet above the pond stage during storms, then fell towards equilibrium with the pond. During the seasonal recessions, water levels in both wells began declining before the pond surface then fell abruptly as the pond drained (fig. 4).

At Westall Swamp, ground-water levels in the upper and lower parts of the Manchester aquifer stayed within 0.2 foot of each other and of the pond surface much of the flooding season (fig. 5). Similar to Sinking Pond, water levels in both wells dropped below the pond surface during the seasonal recessions. Head differences greater than 1 foot between the two wells occurred only when the pond was dry, notably in November and December 1993 (fig. 5).

Water depths in Sinking Pond and Westall Swamp exhibited distinctly bimodal frequency distributions (fig. 6). The deepest part of Sinking Pond had daily mean water depths of 1.5 feet or less for 327 days, or 38 percent of 860 days recorded. Daily mean water depths were greater than 8 feet for 464 days, or 54 percent of the recorded days. Westall Swamp had daily mean water depths of 0.5 foot or less on 385 days, or 45 percent of 853 days recorded. Daily mean water depth exceeded 6.5 feet for 338 days, or about 40 percent of the recorded days.

The hydrograph of Tupelo Swamp differs from those of the sinkhole sites. Water-surface elevations in this shallow depression varied between 1,069.7 feet (fully drained) and 1,073.2 feet above sea level, a range of 3.5 feet (fig. 7). Seasonal flooding generally occurred earlier and persisted longer than in the two sinkhole ponds, and frequencies of flooding depths were more evenly distributed than in Sinking Pond and Westall Swamp (fig. 6).

Table 2. Well-construction data for continuously monitored wells near wetlands at Arnold Air Force Base

[AEDC, Arnold Engineering Development Center; USGS, U.S. Geological Survey; --, no data; SH, shallow aquifer; LMN, lower Manchester aquifer; UMN, upper Manchester aquifer; FP, Fort Payne aquifer]

AEDC well name	Local well number	USGS site identification	Land surface altitude (feet)	Measuring point height (feet)	Surface casing depth (feet)	Depth to bottom of seal (feet)	Screened interval (feet)	Depth to bottom of borehole (feet)	Hydro-geologic unit	Date of construction
AEDC-185	Cf:G-016	352509086051102	1,101.96	0.30	27	47	50 - 60	61	LMN	12-07-90
AEDC-198	Cf:G-032	3522530860119011	1,072.12	1.12	106	115	122 - 132	133	FP	01-18-91
AEDC-200	Cf:G-021	352354086032501	1,067.46	1.24	56	72	74 - 84	84	LMN	12-18-90
AEDC-215	Cf:G-019	352420086024101	1,075.75	1.75	--	46	48 - 58	61	UMN	12-10-90
AEDC-353	Cf:G-062	352441086044501	1,068.01	3.20	26	82	85 - 95	162	LMN	04-22-93
AEDC-354	Cf:G-063	352441086044502	1,067.18	3.49	--	12	13 - 23	24	UMN	04-26-93
AEDC-355	Cf:G-064	3524360860412	1,070.62	3.53	--	20	21 - 31	32	UMN	04-22-93
AEDC-356	Cf:G-065	352458086034702	1,070.40	3.04	--	21	23 - 33	34	UMN	04-26-93
AEDC-357	Cf:G-066	352312086013500	1,069.90	3.06	--	20	20 - 30	31	SH	04-28-93
AEDC-358	Cf:G-067	352507086034501	1,072.61	3.28	--	28	20 - 30	30	UMN	11-03-93
AEDC-359	Cf:G-068	352507086034502	1,073.04	2.98	32	62	75 - 85	85	LMN	11-03-93

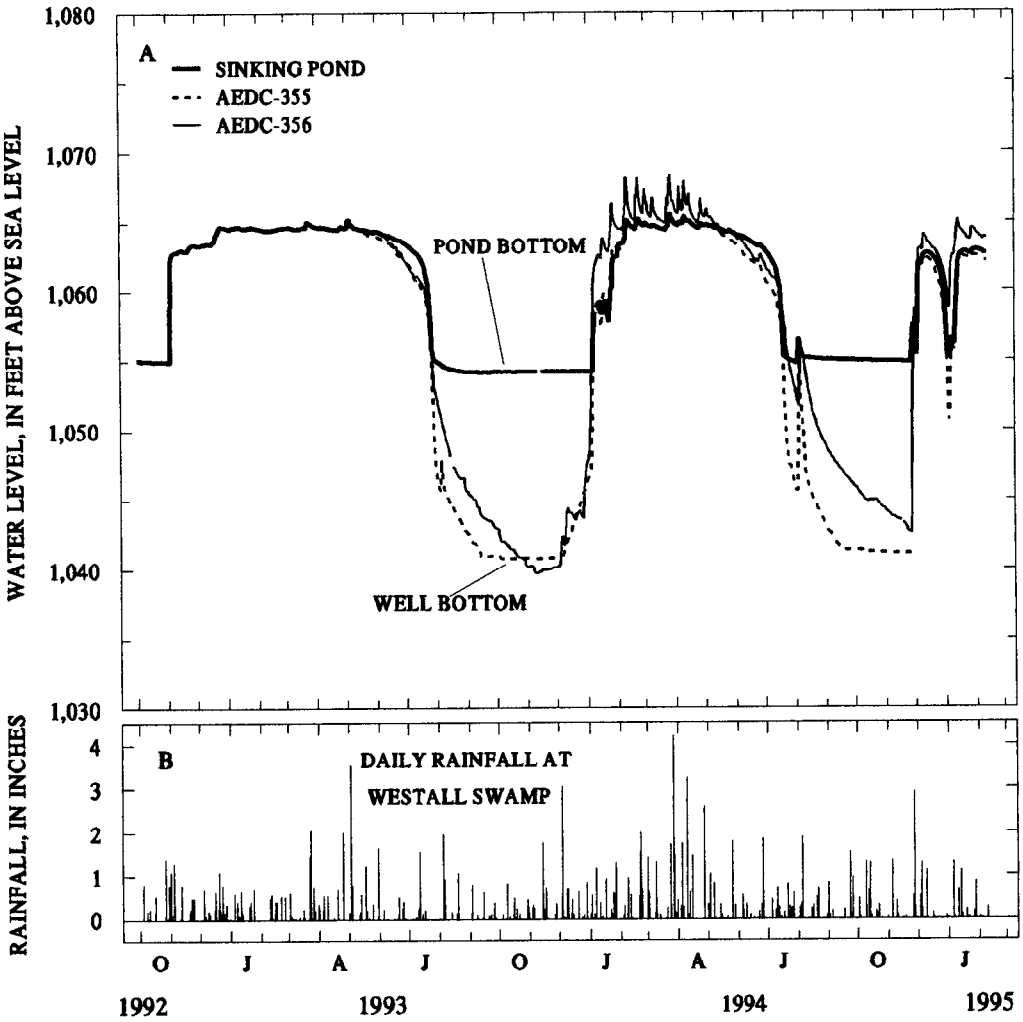

Figure 4. (A) Water levels in Sinking Pond and nearby wells and (B) daily rainfall at Westall Swamp.

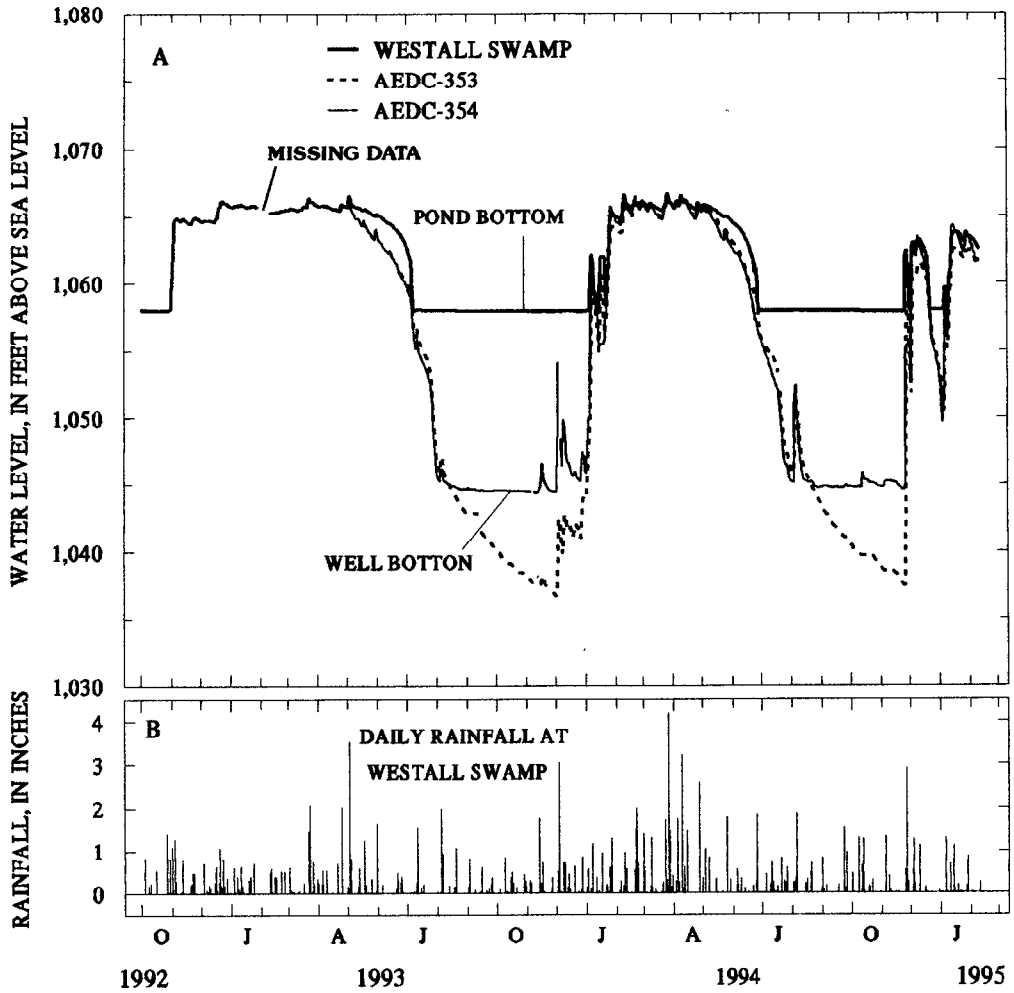

Figure 5. (A) Water levels at Westall Swamp and nearby wells and (B) daily rainfall at Westall Swamp.

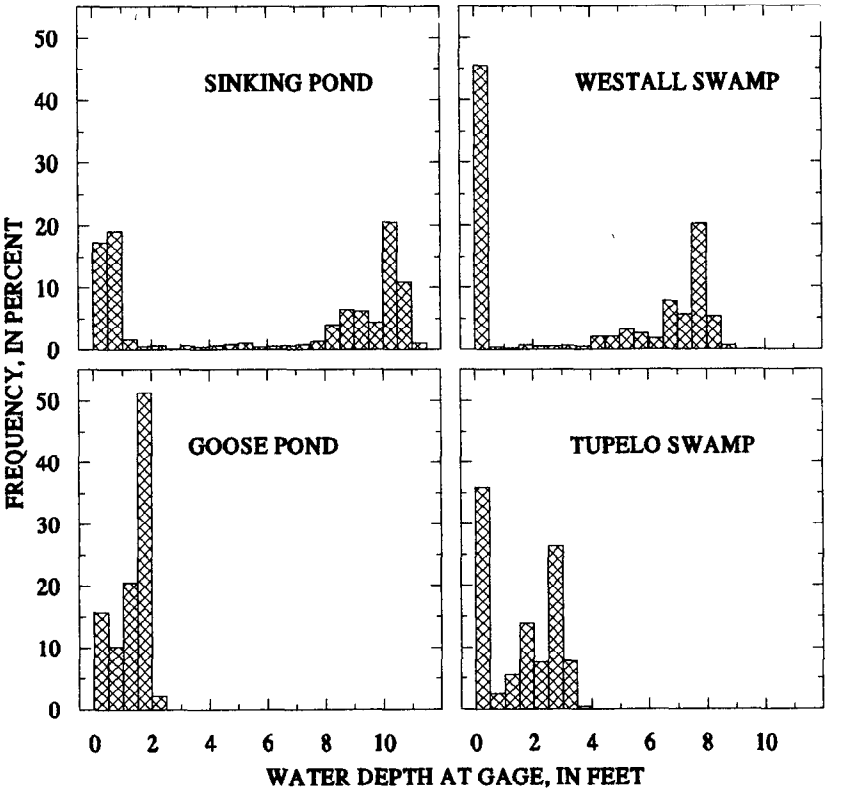

Figure 6. Frequency distributions of recorded water depths in four wetland sites at Arnold Air Force Base.

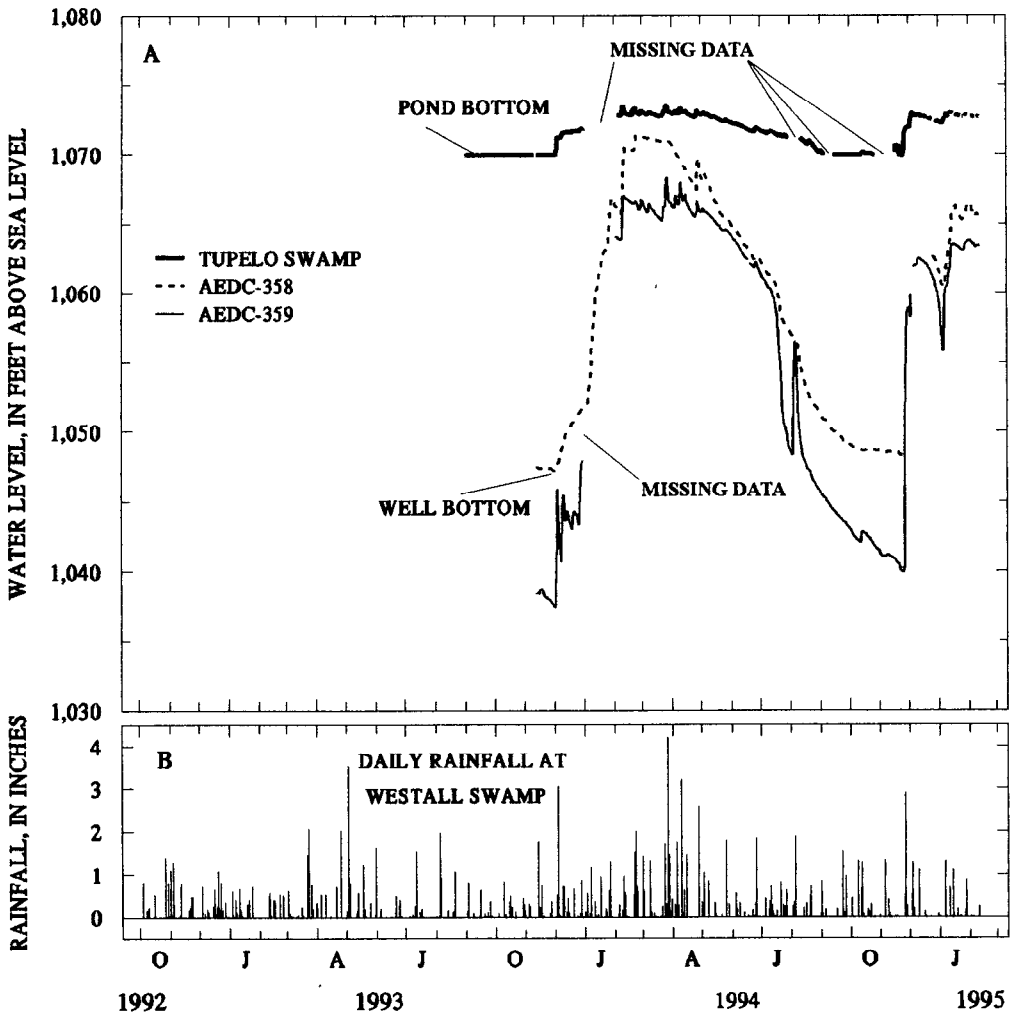

Figure 7. (A) Water levels in Tupelo Swamp and nearby wells and (B) daily rainfall at Westall Swamp.

Water levels in both wells at Tupelo Swamp were subject to rapid rises and falls, essentially simultaneous with the responses of other wells and surface-water levels in the Sinking Pond area (fig. 7). Ground-water elevations in the upper part of the Manchester aquifer were generally higher than those in the lower part; the difference between water levels in the two wells varied seasonally (fig. 7).

The hydrographs for two wells southeast of Sinking Pond, AEDC-200 and AEDC-215, resemble each other in shape and amplitude. A third well, AEDC-185 northwest of Westall Swamp, displays a hydrograph similar in shape but with a smaller range than the first two (fig. 8). Rises and recession at all three wells were less abrupt than those in the wells at Sinking Pond and Westall Swamp (figs. 4 and 5).

The two streamflow stations in the Sinking Pond area showed relatively rapid fluctuations in discharge. During the winter and early spring months of 1993 and 1994, peak discharges at the Sinking Pond outflow gage south of Sinking Pond ranged from less than 5 ft^3/s to more than 40 ft^3/s (fig. 9). Discharge remained less than 1 ft^3/s during the fall and early winter months of 1994-95 (fig. 9).

Discharge at the Sinking Pond inflow gage, located on a channel flowing from Tupelo Swamp into Sinking Pond, remained less than 5 ft^3/s throughout the period of record. Peak flow at this station reached or exceeded 3.5 ft^3/s during four storms between January and June 1994 (fig. 10), and exceeded 1 ft^3/s only once between October 1994 and February 1995 (fig. 10).

Surface-water elevations in Goose Pond ranged from 1,066.9 to 1,069.2 feet above sea level (fig. 11). The difference between minimum and maximum recorded stage was 2.3 feet, the narrowest range of the four continuously monitored wetland sites. The frequency of daily mean water depth in Goose Pond was relatively evenly distributed (fig. 6). The pond bottom remained saturated within 0.5 foot of the surface throughout the study period. In general, the surface-water hydrograph for this site resembled that of Tupelo Swamp but differed significantly from those of Sinking Pond and Westall Swamp (fig. 12).

Water levels in nearby wells remained consistently below Goose Pond stage throughout the study period. The hydrograph for the shallow-aquifer well (AEDC-357) next to the Goose Pond gage displays relatively steady rises and falls and a lag in its response to rainfall events compared to that of the pond (fig. 11). Water levels in well AEDC-198, about 0.75 mile southeast of Goose Pond and screened in the Fort Payne aquifer, were consistently 20 to 30 feet below the water surface of Goose Pond and lower than water levels in the shallow well at Goose Pond (fig. 11).

SUMMARY

Surface-water stage and flow, rainfall, and ground-water levels were measured at or near four wetland sites at AAFB. Data were collected to provide information on the interaction of the wetlands with the local ground-water system and to evaluate wetland water regimes

Sinking Pond and Westall Swamp include well developed sinkholes with steep sides and internal relief of 7 feet or more. These sites were characterized by rapid rises and recessions of water levels—about 7 feet in 24 hours at Sinking Pond and 5 feet in 24 hours at Westall Swamp. Ground-water and surface-water elevations closely tracked each other at both wetlands during periods of high surface-water stage. During the seasonal recession, ground-water elevations fell 15 to 20 feet below the bottom elevations of the two wetlands.

Tupelo Swamp and Goose Pond are shallow depressions with longer, more persistent periods of flooding. Maximum recorded water depths were 3.5 feet at Tupelo Swamp and 2.3 feet at Goose Pond. Ground-water levels at the two sites remained lower than surface-water stage.

Surface-water flow into and out of Sinking Pond occurred primarily during winter and early spring. Flow from Tupelo Swamp into Sinking Pond never exceeded 5 ft^3/s. Flow at a gage downstream of Sinking Pond ranged from less than 5 to more than 40 ft^3/s.

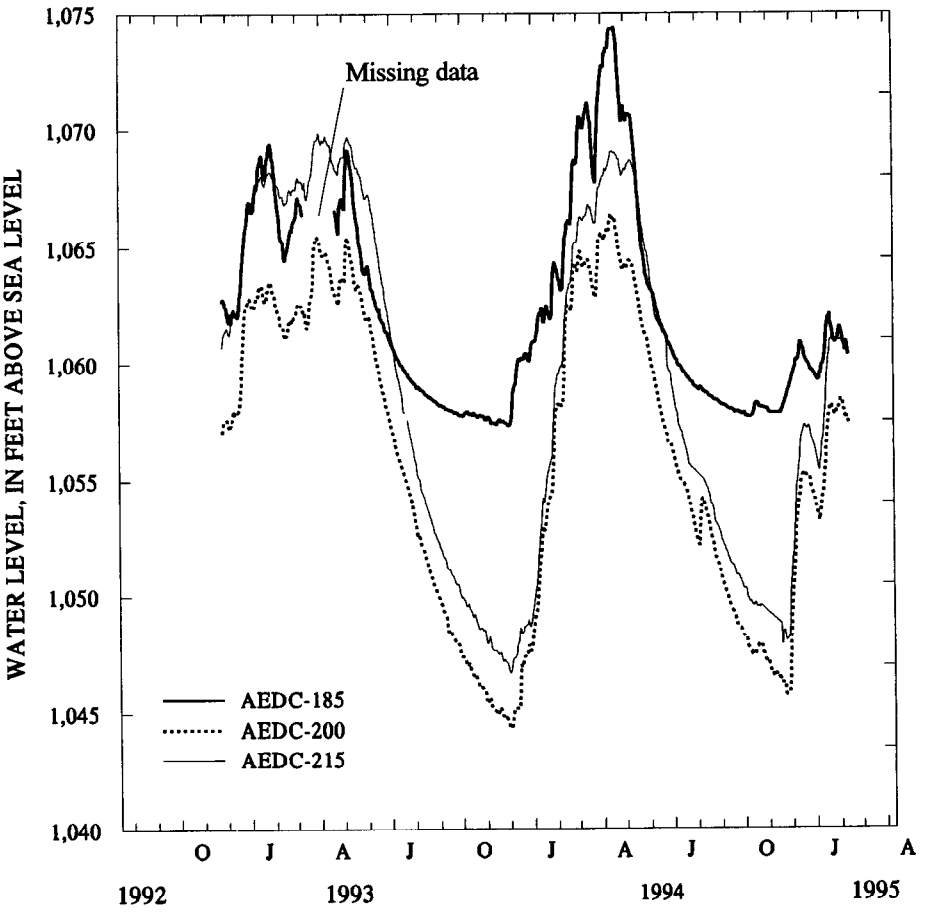

Figure 8. Hydrographs for three wells in the northern part of Arnold Air Force Base.

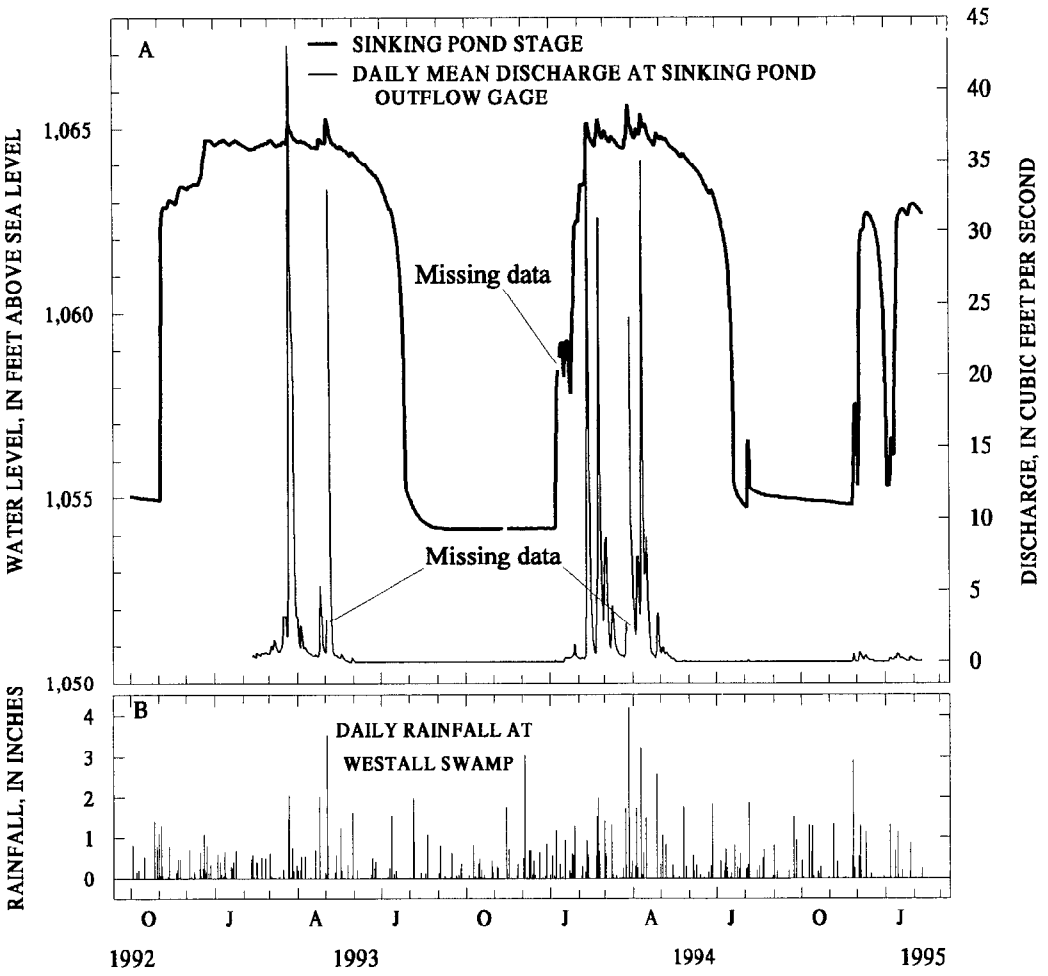

Figure 9. Relation of discharge at Sinking Pond outflow gage to (A) stage in Sinking Pond and (B) rainfall at Westall Swamp.

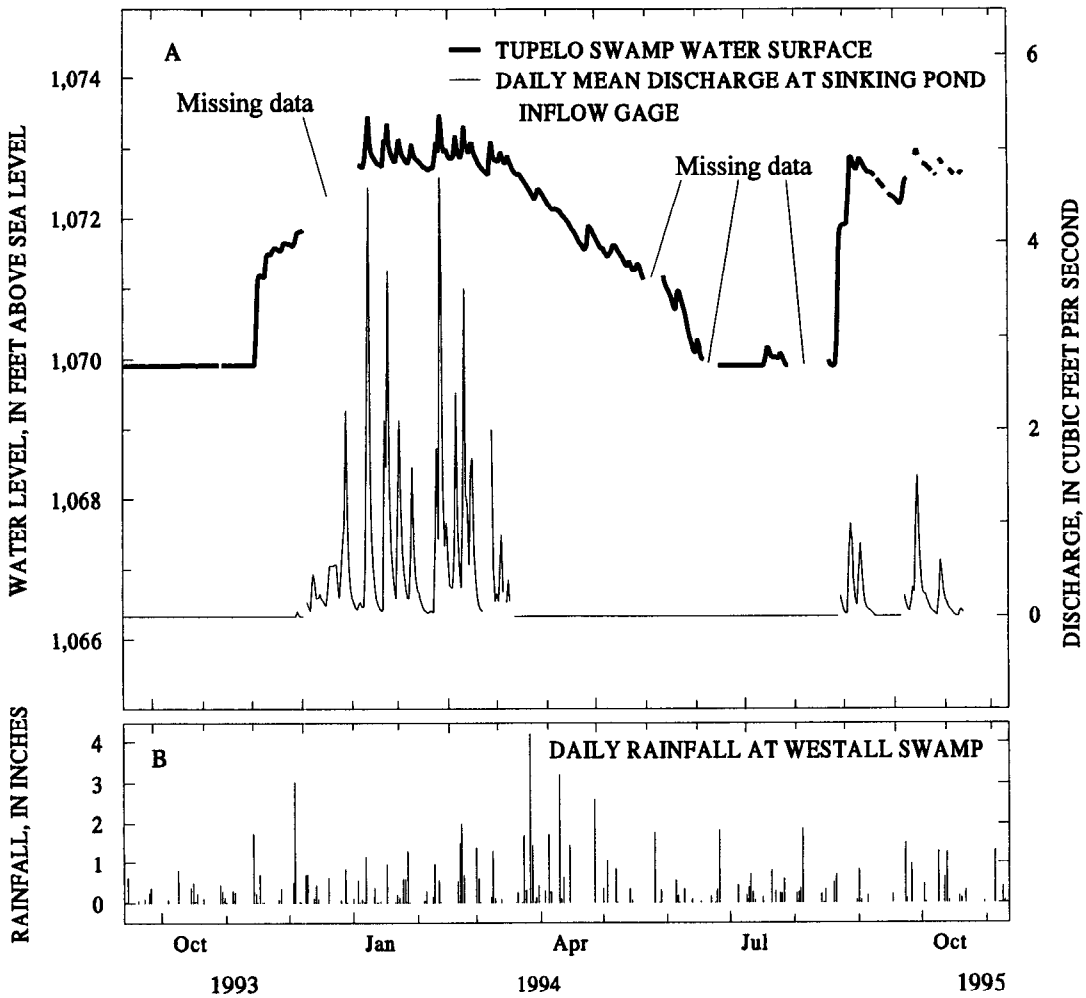

Figure 10. Relation of discharge at Sinking Pond inflow gage to (A) stage in Tupelo Swamp and (B) rainfall at Westall Swamp.

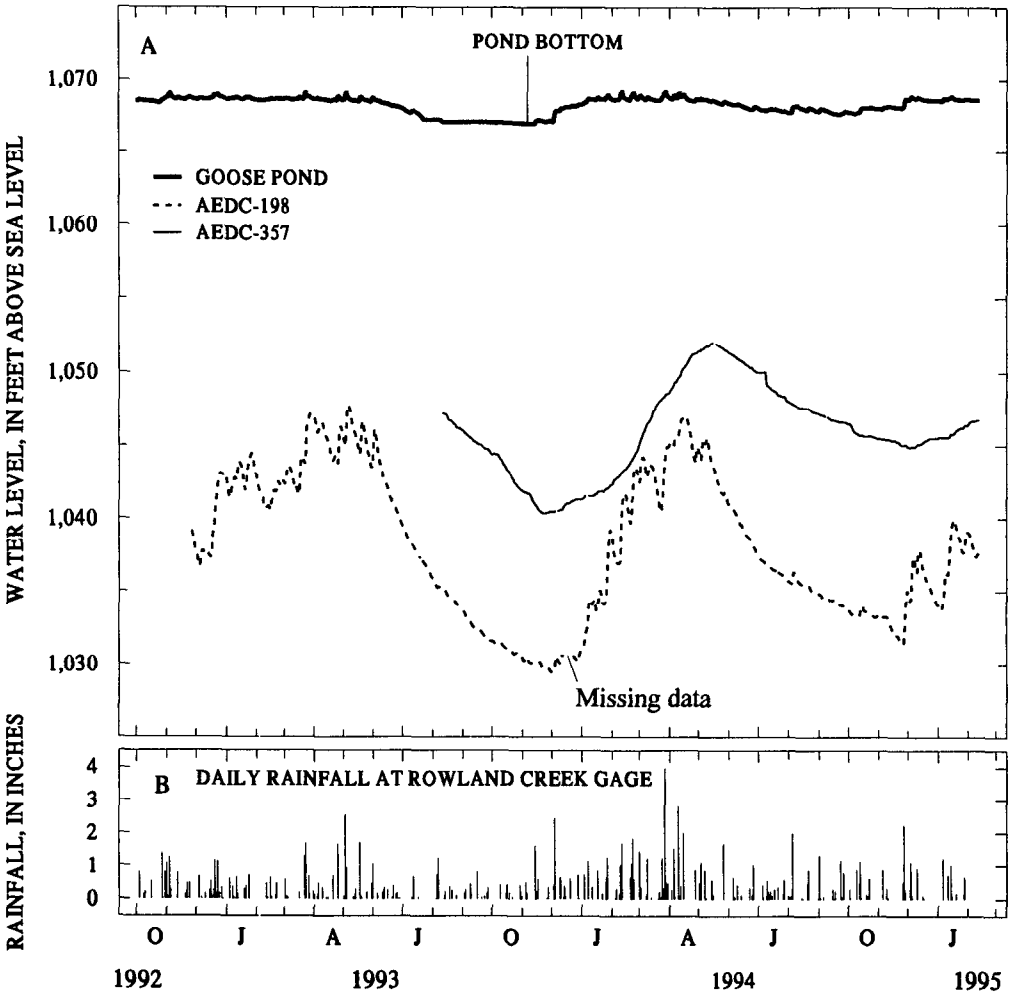

Figure 11. (A) Water levels in Goose Pond and nearby wells and (B) daily rainfall at Rowland Creek streamflow gage.

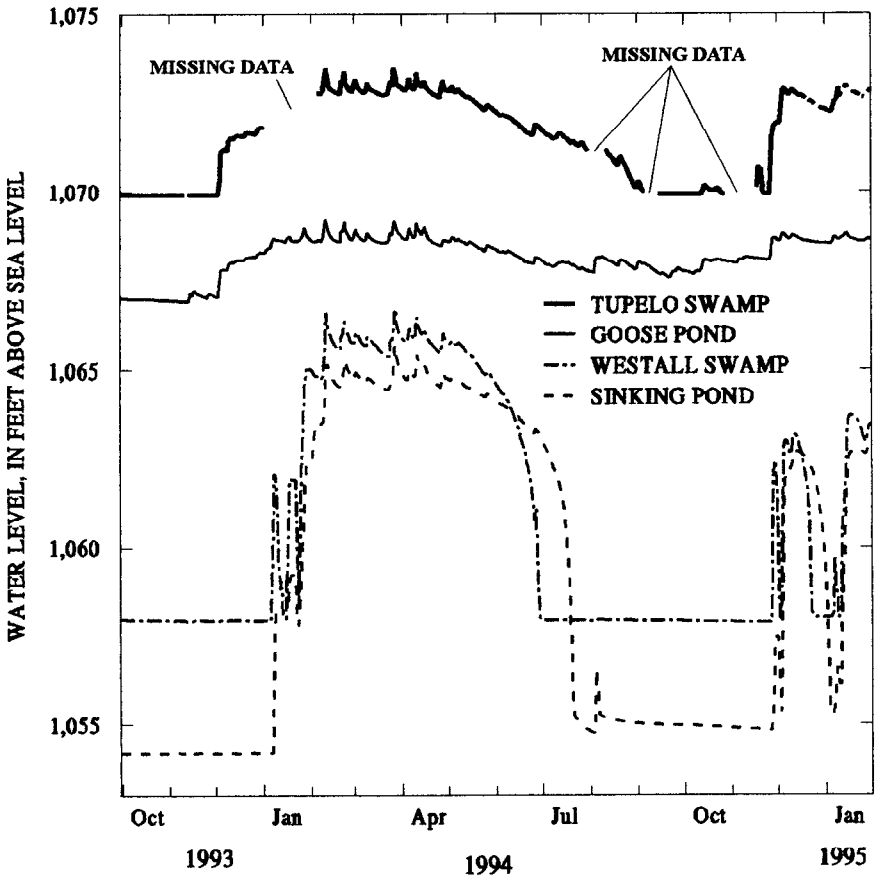

Figure 12. Comparison of hydrographs for four wetland sites at Arnold Air Force Base for period October 1993 through January 1995.

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